CoER : Biofuels

Department of Microbiology • Faculty of Natural Sciences

# Plant biomass into bioenergy– Technologies and Biorefineries

**WH (Emile) Van Zyl*[1], JF Görgens[2], M Bloom[1], H von Blottnitz[3], JH Knoetze[2], AFA Chimphango[2]**

SANERI Senior Chair in Energy Research in Biofuels Programme at Departments of [1]Microbiology and [2]Process Engineering, University of Stellenbosch and [3]Department of Chemical Engineering, University of Cape Town

# Plant biomass into bioenergy

1. Non-sustainable future

2. Biological and Thermochemical technologies for bioenergy/biofuels production

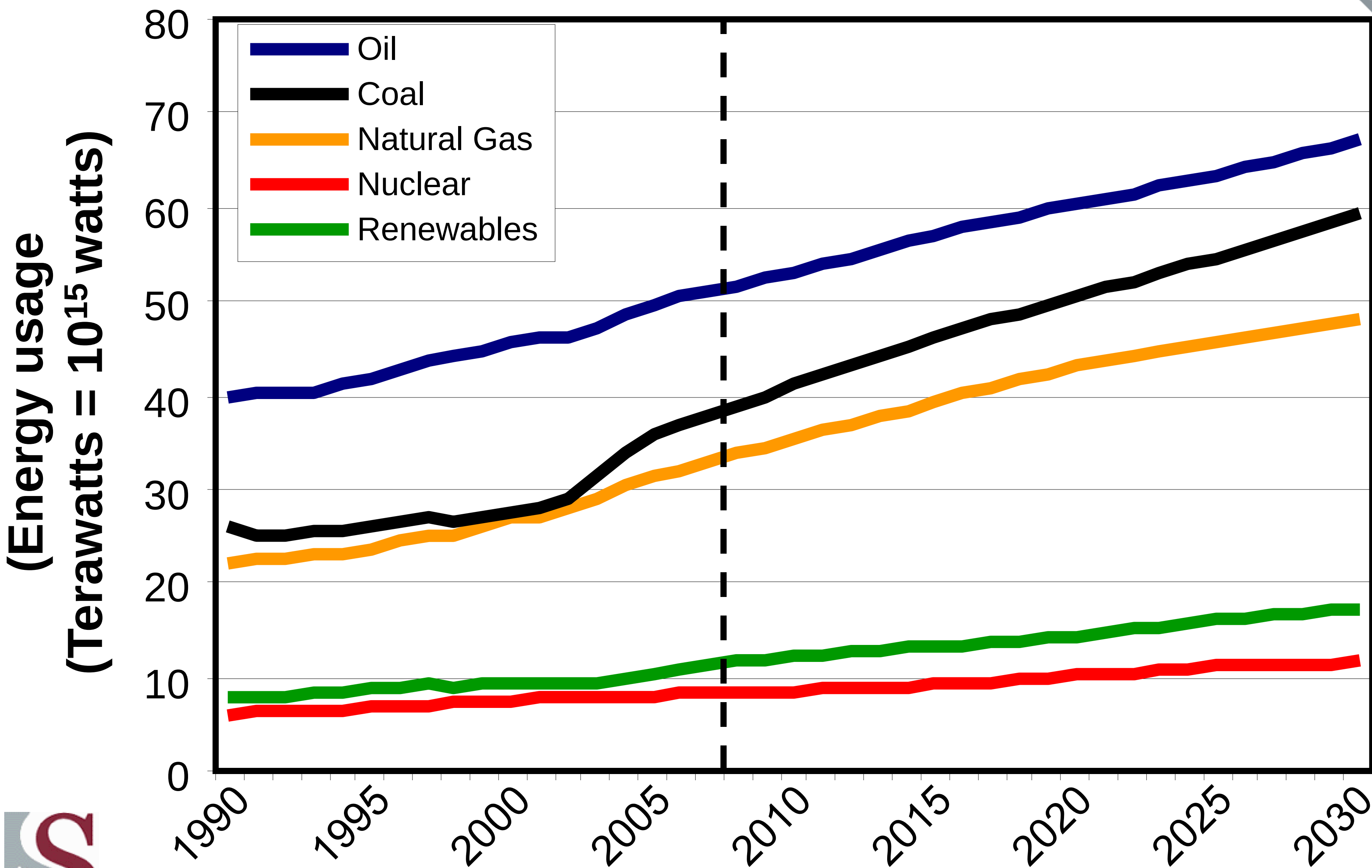
3. Can we afford bioenergy production with limited land?

4. What have biorefineries to offer?

5. SANERI Chair of Energy Research : Biofuels and other clear fuels

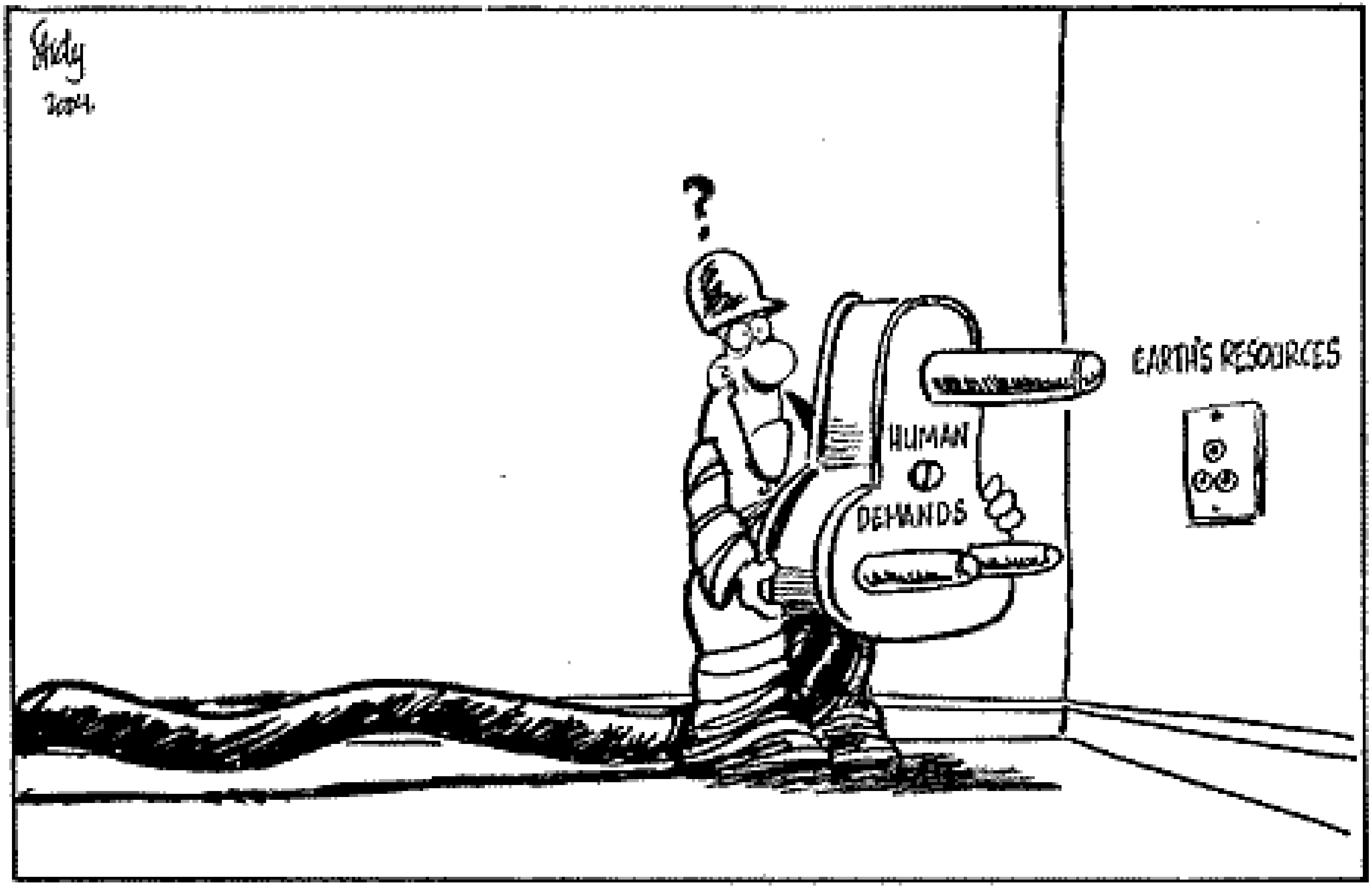
# Non-sustainable future

# Total global energy consumption

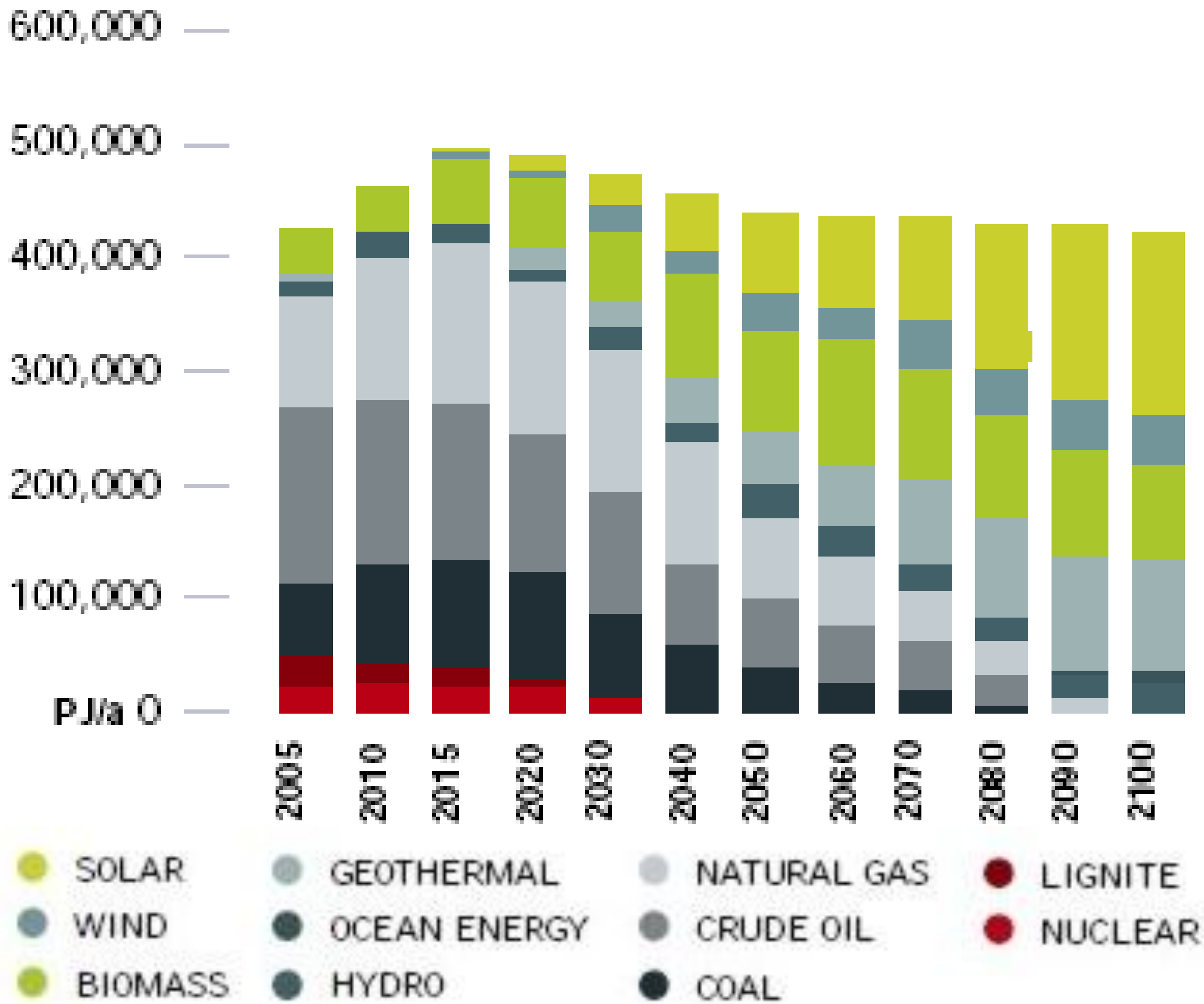



**Source:** International Energy Outlook 2008 (www.eia.doe.gov/)

# We are heading for a non-sustainable future!



# [R]evolutionary scenario until 2090



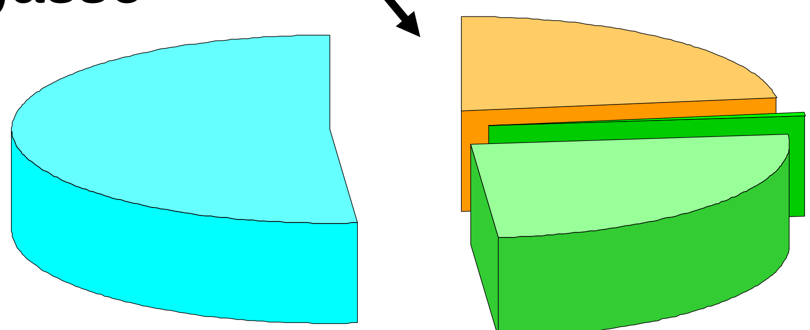

**Source:** Energy [r]evolution: A sustainable global energy outlook (EREC = European Renewable Energy Council & Greenpeace)

# Microbial Technologies for Cellulosic Ethanol Production

# Technologies for Cellulose Conversion

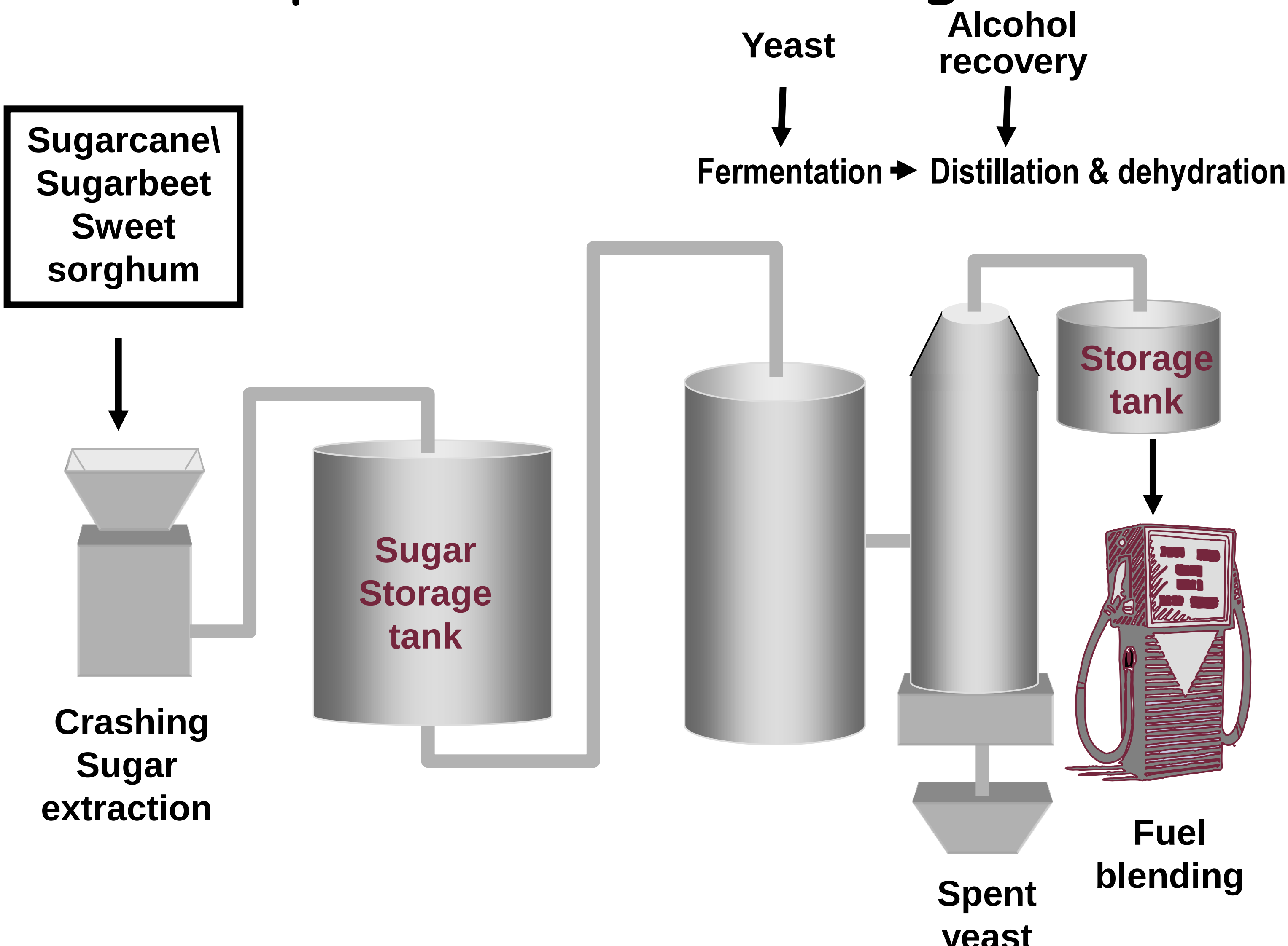
## Lignocellulose composition

*Sugarcane bagasse*

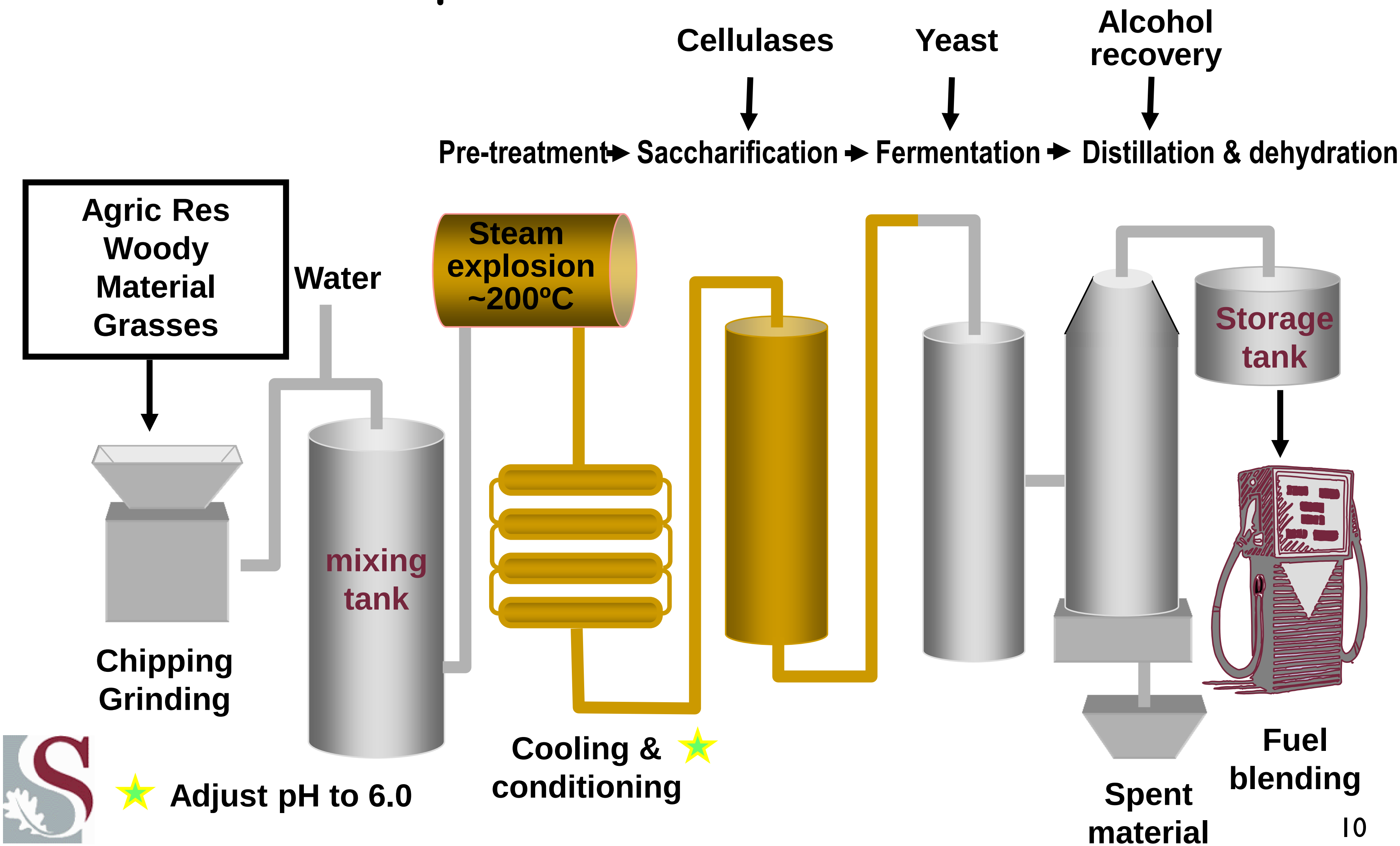


# Technologies for Ethanol Production

## Ethanol production from sugar

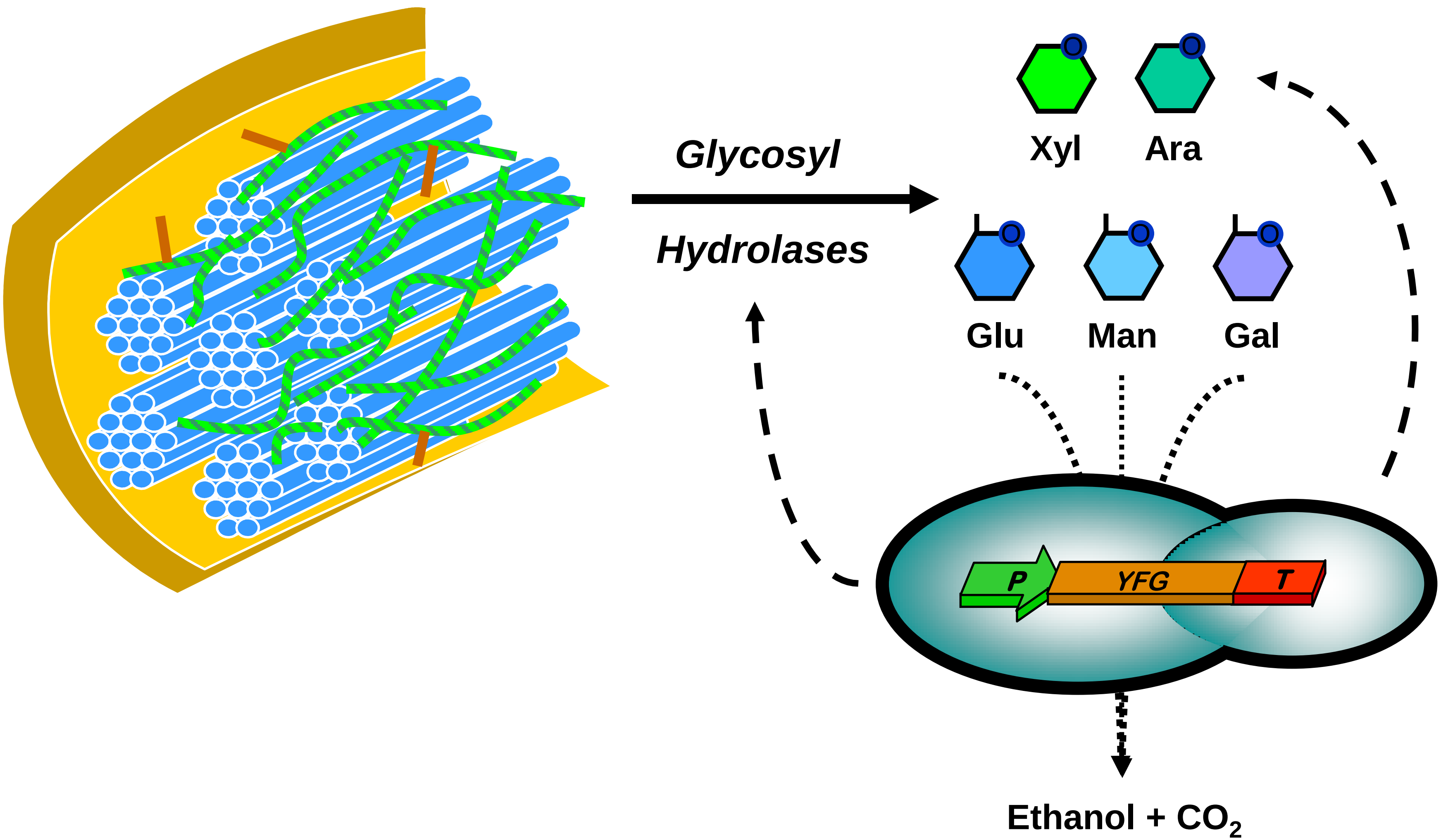


# Ethanol production from cellulosics



# Technologies for Cellulose Conversion

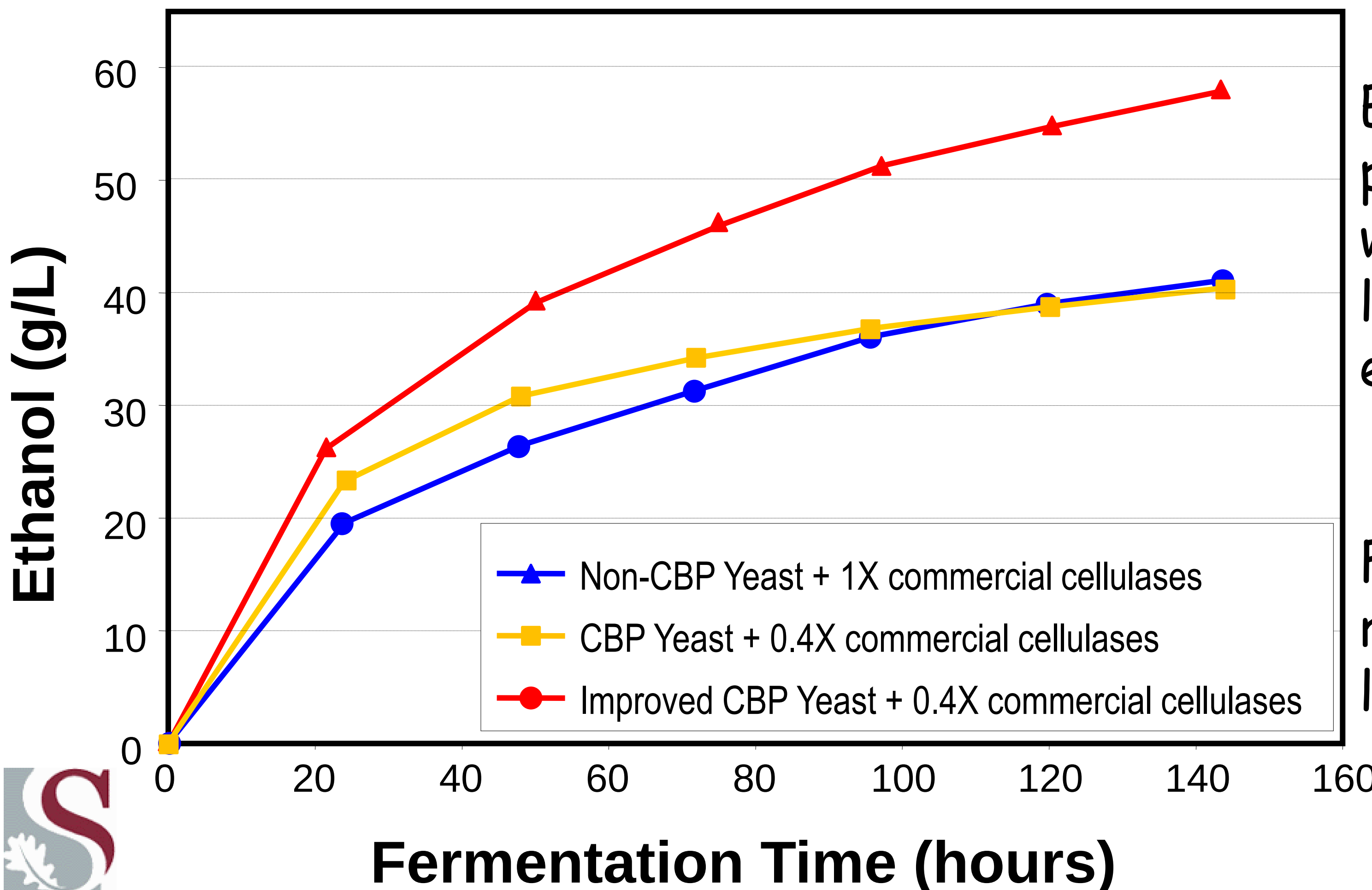
## Consolidated BioProcessing (CBP)



Mascoma Corporation
Technical facilities, Lebanon, NH, USA
(www.mascoma.com)

# Enzyme Reduction on Hardwood

Mascoma CBP Strain (robust C5/C6 fermenting yeast) + 22% w/w unwashed Pretreated Hardwood




Equivalent performance with 2.5-fold less added enzyme

Further reduction likely

MASCOMA

# Rome, NY Pilot & Demonstration Plant

January 2008

November 2008

# Biological conversion of biomass to Biogas

# Biogas

- **Biogas** typically refers to a gas produced by the biological breakdown of organic in the absence of oxygen (thus anaerobically). Biogas is thus a type of biofuel, whereas natural gas is a fossil fuel!
- Biogas is typically produced by anaerobic digestion or fermentation of biomass, manure, sewage, municipal waste, or even sugar streams and energy crops. This type of biogas produced comprises primarily of methane (55-60%) and $CO_2$ (35-40%).
- Biogas is a renewable fuel, that is used for cooking, to produce electricity and for transport (compressed).

# Biogas

- However, methane is 20 times more potent as a greenhouse gas than $CO_2$. Therefore uncontained landfill gas which escapes into the atmosphere may significantly contribute to the effects of global warming.
- For the production of biogas mixed municipal waste, manure and waste streams from other bioprocesses are usually considered.

# Thermochemical Technologies for Biofuel Production

# Thermochemical technologies for Cellulose

## Conversion Technologies

### Lignocellulose thermo-chemical processes

1. Combustion involves the burning of biomass in the presence of $O_2$ with the harvesting of the released energy as primarily heat, or generating steam.
2. Fast Pyrolysis involves the heating of biomass for few seconds to about 500°C in the absence of $O_2$, followed by rapid cooling. The result is the formation of primarily,bio-oil from condensation of vapours during rapid cooling, biogas and solids called char.
3. Gasification is taking place at higher temperatures for longer in the presence of $O_2$, which yields syngas for Fischer-Tropsch synthesis (SASOL).

# Application of Thermochemical Processes

- Both the pure lignocellulose and lignin-rich residues from lignocellulose fermentation can be processed. Less sensitive to source of lignocellulose.
- Three products streams are generated:
  - Bio-oil (liquid phase) – composed of large variety of chemicals, including phenols, aromatics, organic acids and furans amongst others.  Bio-oil can substantially reduce transportation costs since it got 2-fold energy-densification on a volume basis and can be pumped;
  - Biogas (gas phase) – composed of incondensable gasses ($CO$, $CO_2$, $CH_4$) that can be use for heat generation;
  - Biochar (solid phase) - activated carbon that can be used for soil amendment or heat generation

# Current status on Thermochemical Processes

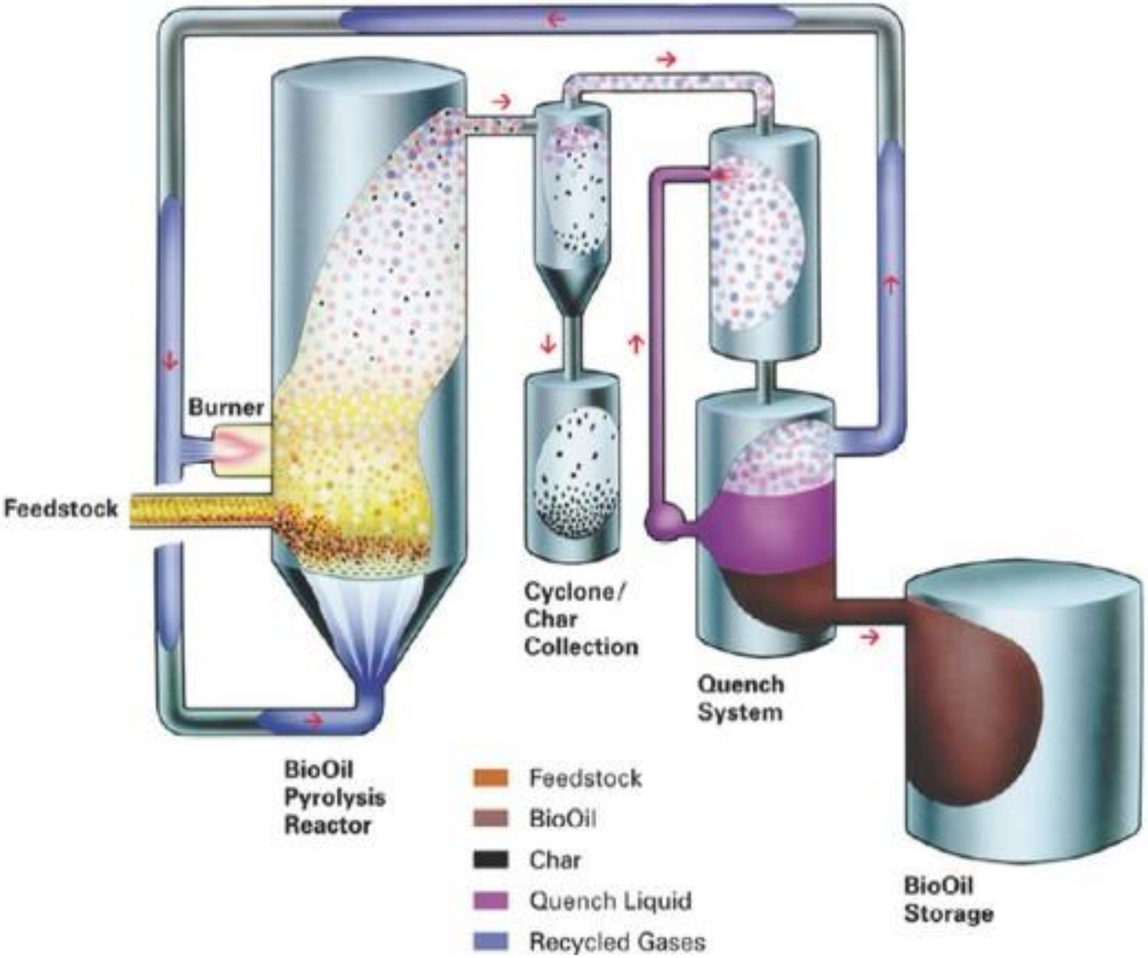
## Vacuum pyrolysis:

- small batch lab unit (±100 g) (15kPa abs and Temp 300-450°C) – operational since 2002.
- In SANERI project with Dr J Klaasen from UWC looked at kraalbos and renosterbos.
- Looked at some pioneer/intruder plants, sewage sludge and bagasse.
- Yields typically 25-35% char, 25-35% bio-oil.

## Fast Pyrolysis:

- Commissioning small bench-scale set-up.
- Looking at bagasse, corn cobs and soon Eucalyptis.
- Fast Pyrolysis: < 10% char (high in ash), mostly bio-oil.

# Thermo-Conversion Technologies



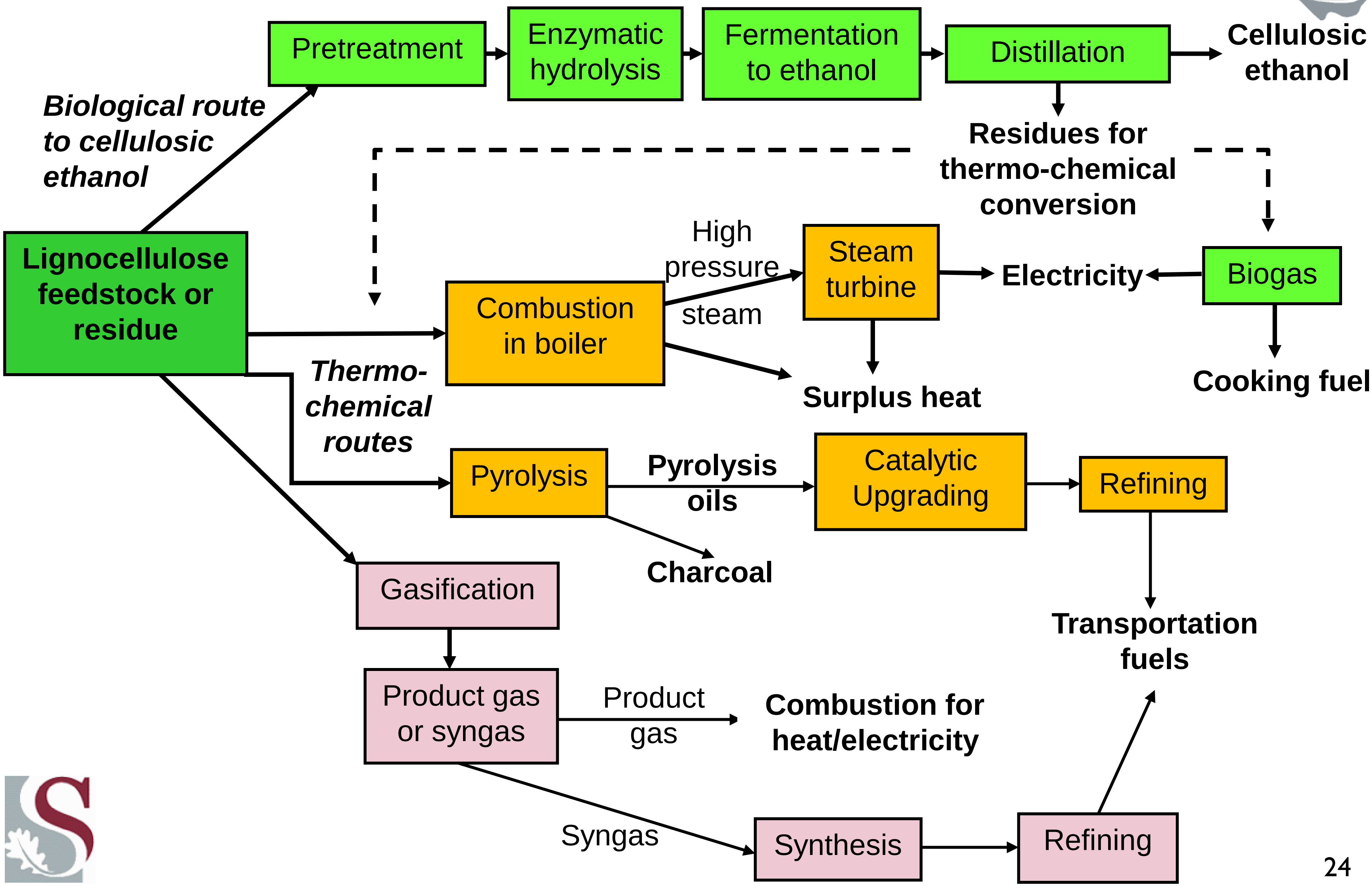

# Thermo-Conversion Technologies

Bio-oil

Char

Viscous/dense bio-oil

# Biomass Conversion Options



# Can we afford bioenergy production with limited land?

# Plant biomass into bioenergy

An astonishing YES, providing:

1. Technologies are developed for the conversion of more abundant woody plant biomass (called lignocellulosics) and organic waste streams to commodity products, fine chemicals, a bioenergy;
2. Plant breeders and environmentalists (and plant biotechnologists?) work together to develop and manage sustainable bio-energy crops, and last but not least;
3. *We learn to adapt a more energy-conservative life style.* For the purpose of this discussion the focus is primarily on the technological challenges, because the latter requires behavioural changes all world societies have to deal with, including South Africans!

# South Africa's potential:
## Renewable biomass available

| | |
|---|---|
| 1. Residues | |
| Agricultural | |
| Maize stover | 6.7 Mt/a |
| Sugar cane bagasse | 3.3 Mt/a |
| Wheat straw | 1.6 Mt/a |
| Sunflower stalks | 0.6 Mt/a |
| **Agricultural subtotal** | **12.3 Mt/a** |
| Forest industry | |
| Left in forest | 4.0 Mt/a |
| Saw mill residue | 0.9 Mt/a |
| Paper & board mill sludge | 0.1 Mt/a |
| **Forest industry subtotal** | **5.0 Mt/a** |
| 2. Energy crops | |
| From 10% of available land (Marrison and Larson, 1996) | **67 Mt/a** |
| 3. Invasive plant species | **8.7 Mt** |
| **Total, annual basis** | **93 Mt/a** |

**Lynd et al.** 2003. Plant Biomass Conversion to Fuels and Commodity Chemicals in South Africa: A Third Chapter? South African Journal of Science **99:** 499 – 507.

# South Africa's potential:
## Municipal organic wastes

1. Waste generation in SA amounts to >400 Mt per annum, of which 1.5% is domestic and trade waste and 0.1% sewage sludge. The middle class in South Africa generates about 2.7 Mt domestic waste per year - about 0.7 kg/person/day![1]

2. The six largest metropolitan municipalities in South Africa dispose of 8.9 Mt of solid waste per year, of which the organic fraction is about 40%!

2. The scarcity of landfill areas close to cities, uncontrolled leachate in groundwater and $CH_4$ generated from these landfills, together with a growing need for renewable energy, makes the production of biogas an attractive option

[1] **Greben et al.** 2009. Unlocking the resource potential of organic waste: a South African perspective**.** Waste Management & Research ***27:*** *676 – 684.*

[2] **Von Blottnitz** et al. 2006. Burn, Gasify, Pyrolyse or Ferment? Making sense of the many possibilities for energy from waste in South Africa. WasteCon06, Somerset West, 5-8 September 2006.

# What have biorefineries to offer?

# Biorefineries in a sustainable future

**Biorefining** is the sustainable processing of **biomass** into a spectrum of bio-based products (food, feed, chemicals, materials) and bioenergy (biofuels, power and/or heat).

A **biorefinery** is thus a facility that integrates biomass conversion processes and equipment to produce bio-based products  and bioenergy from biomass, analogous to today's petroleum refinery, which produce multiple fuels and products from fossil fuels (crude oil, coal or natural gas).

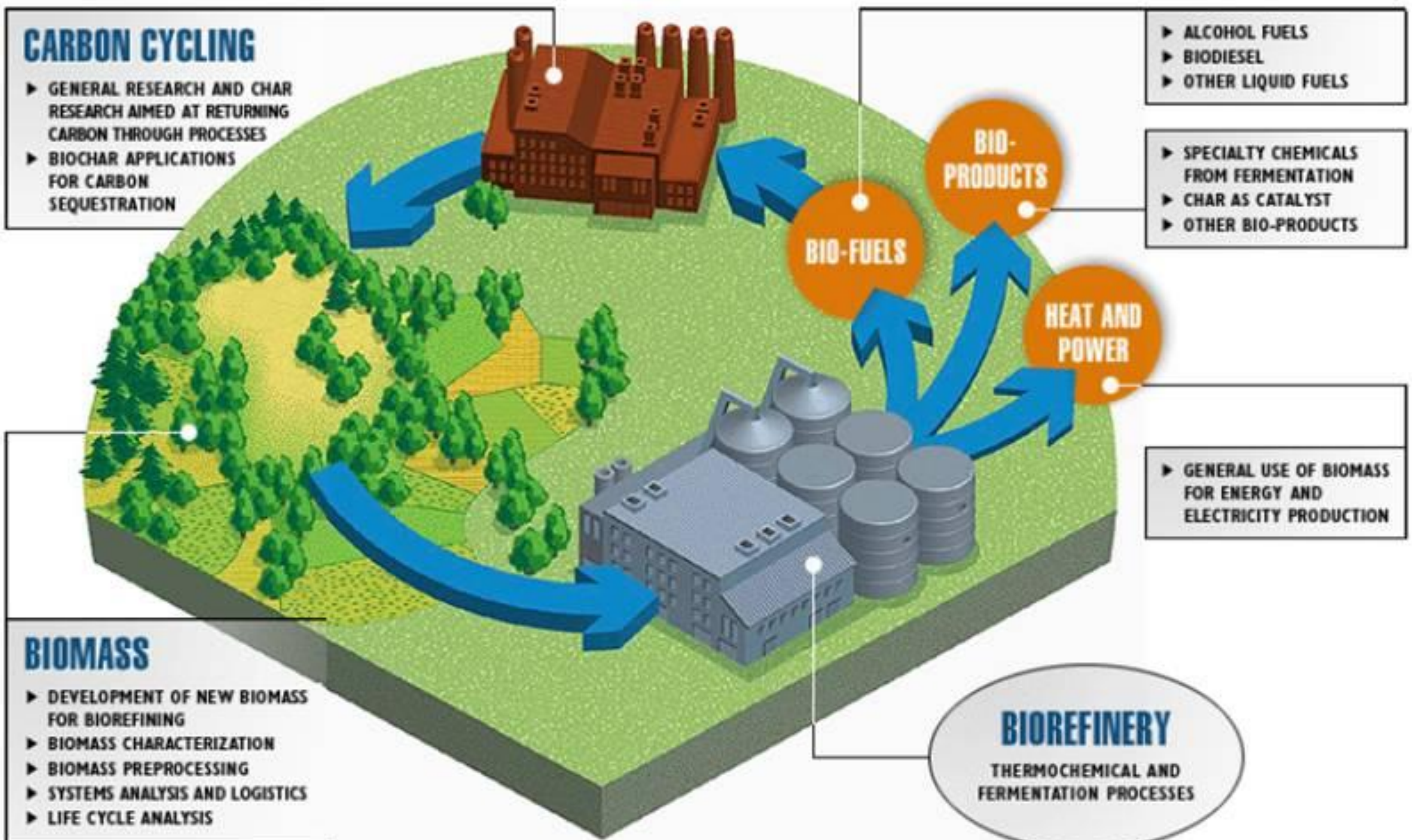
# Biorefineries in a sustainable future

1. By producing multiple products, a biorefinery takes advantage of the various components in biomass and their intermediates therefore maximizing the value derived from the biomass feedstock.
2. A biorefinery could, for example, produce one or several low-volume, but high-value, chemical or nutraceutical products and a low-value, but high-volume liquid transportation fuel such as biodiesel, bioethanol or synthetic biofuels (products from chemically or thermochemically modifying sugars).
3. At the same time generating electricity and process heat, through combined heat and power (CHP) technology, for its own use and perhaps enough for sale of electricity to the local utility.

# Biorefineries in a sustainable future

1. The high-value products increase profitability, the high-volume fuel helps meet energy needs, and the power production helps to lower energy costs and reduce GHG emissions from traditional power plant facilities.
2. Although some facilities exist that can be called bio-refineries, the bio-refinery has yet to be fully realized. Future biorefineries may play a major role in producing chemicals and materials that are traditionally produced from fossil fuels.

# Biorefineries in a sustainable future




Biorefining and Carbon cycling program,
University of Georgia (http://www.biorefinery.uga.edu/)

# Benefits of the Biobased Economy

## Economic

- Reduce cost, better control of product properties
- New product and market opportunities
- Improved balance of trade and energy independence

## Environmental

- Pollution prevention, reduced emissions of GHG and toxics
- 'Green' fuels, chemicals and materials
- Reusable and recyclable products

## Social

- Rural economic diversification and growth
- Developing countries can access the bio-based economy
- Improvements in human/environmental health and quality of life

# Biorefinery Feedstock & Product Options

**Starch-rich (grains)**
- (e.g.) maize/sorghum

→ Ethanol & $CO_2$; Animal feed; Co-products*

**Oil Seeds**
- soya beans
- canola/ sun flower

→ Biodiesel; Animal feed; Glycerin, (co-products)

**Sugar-rich**
- sugar cane
- sweet sorghum

→ Ethanol & $CO_2$; (co-products); Lignin-rich residues → Process energy (Electricity &/or Bio-oil/Char)

**Cellulosic**

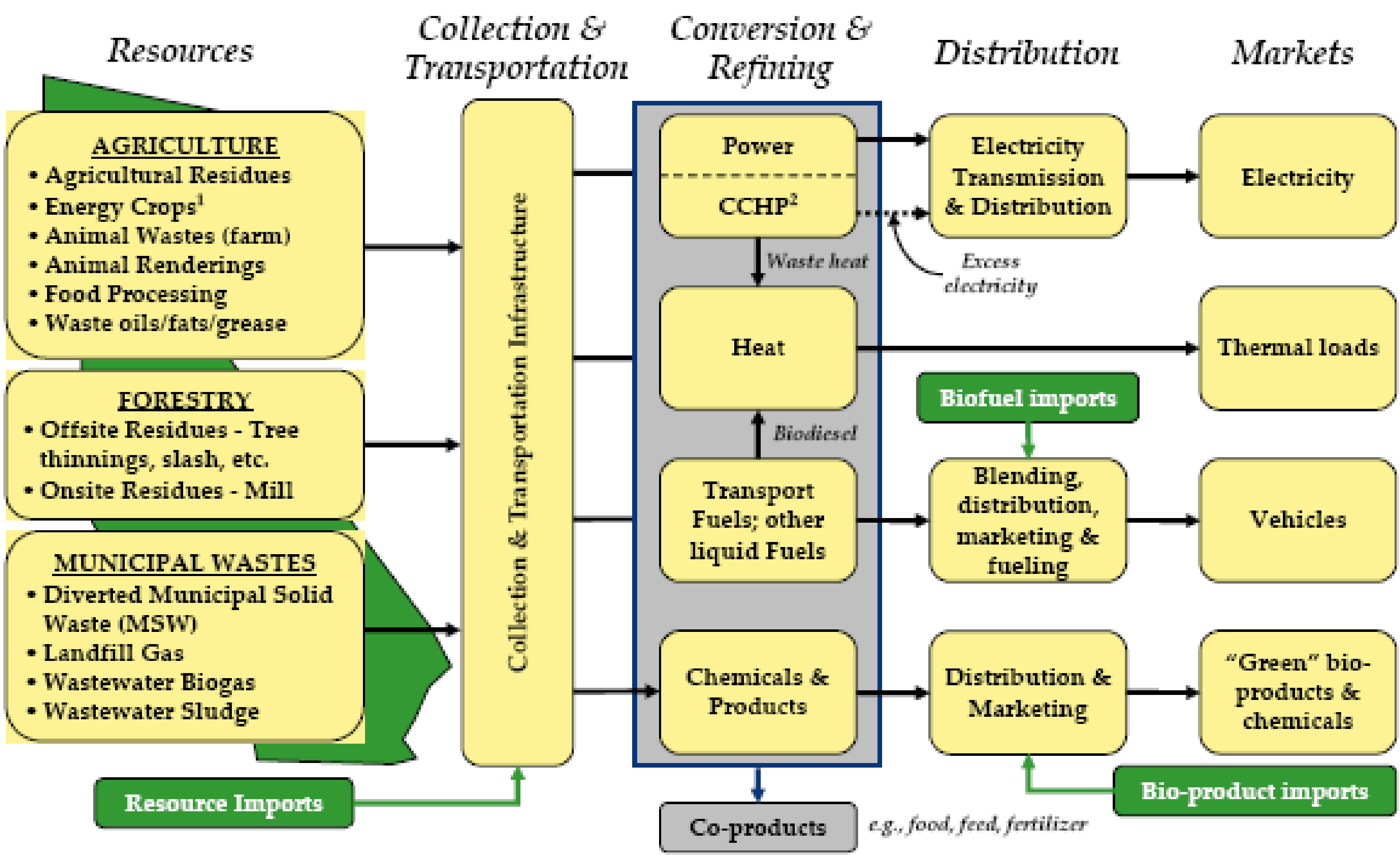
*Residues*
- stover, bagasse
- paper sludge

*Energy Crops*
- grasses
- intruder plants

→ Ethanol & $CO_2$; (co-products, feed); Lignin-rich residues → Process energy (Electricity &/or Bio-oil/Char)

**Coproducts may include industrial or ag. chemicals, sweeteners, neutraceuticals…*

# Simplified Bio-energy Industry Structure




Courteous of Tim Baye, University Wisconsin / Wisconsin Bioenergy Initiative

# Integrating 1st and 2nd generation technologies will create opportunities for southern Africa

# Examples of 1st & 2nd generation integrated

**Considering 10 000 Ha yield commercial variety sugarcane at 100 t/Ha. That will yield per hectare***

- 12 t sucrose = 6.84 kL EtOH = 145.1 EJ (30%)
- 4 t molasses = 2.28 kL EtOH = 63.4 EJ (13%)
- 15 t dry matter = ±4.20 kL EtOH = 270.1 EJ (57%)

- If only fermenting molasses = 68 ML ethanol
- If fermenting all sugars = 91 ML ethanol
- If fermenting all sugars and bagasse = 133 ML ethanol
- Can still use the remaining lignin and waste materials for energy and biogas production

[* Information from Frikkie Botha – SASRI, South Africa]
[Assume ethanol yield from sucrose 570L/t and bagasse 280L/t]

# Opportunities for sugarcane in SADC

- At present, South Africa produce about half of the sugarcane in SADC (20 Mt/annum), using an area of about 325 000 Ha.
- However, a recent study (Watson, 2010) estimated that about 6 MHa of arable land in SADC countries (primarily Mozambique, Angola, Tanzania, Zambia, Zimbabwe and Malawi) are suitable for sugarcane production at an average yield of 65 t/Ha or more.
- Conservatively, this means that the total South Africa sugar industry can be replicated every year for at least 15 -20 years! This also means SADC has the potential to match Brazil in sugar/bioethanol production capacity and that available land/water is not the limiting factor.

**Watson.** 2010. Potential to expand sustainable bioenergy from sugarcane in southern Africa. Energy Policy in press [doi: 10.1016/j.enpol.2010.07.035].

# Example of Biorefinery that works!

*Courtesy of Björn Alriksson, Processum, Sweden*

**Domsjö**


**We make more from the tree!**

*Courtesy of Björn Alriksson, Processum, Sweden*

# New products of Domsjö

**Specialty cellulose**

Competes with cotton and oil based products

**Lignosulfonate**

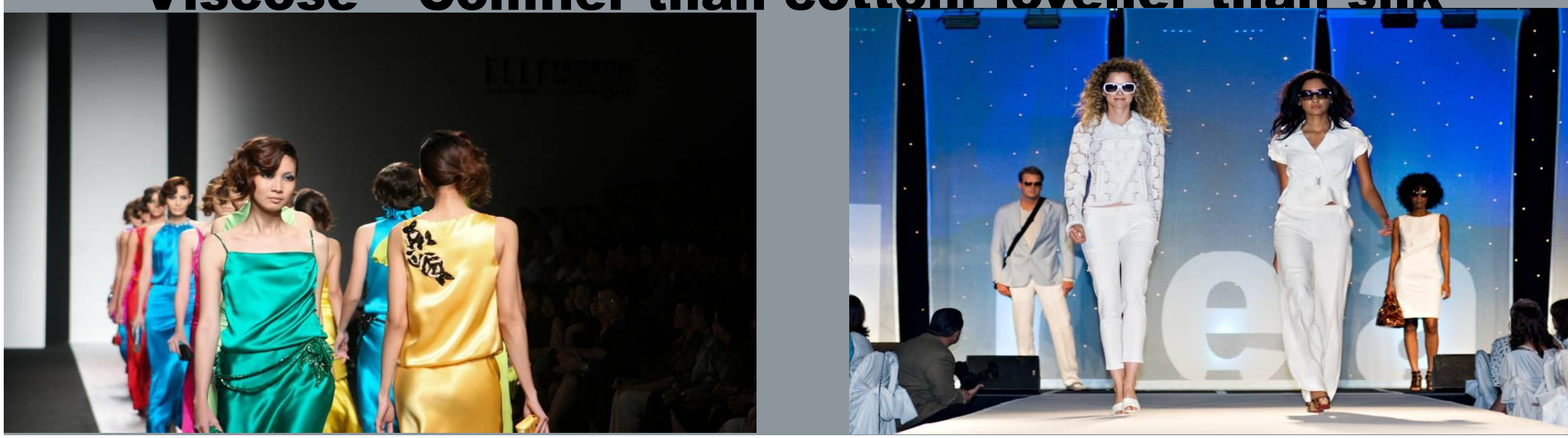
Competes in same segments with oil based products

**Ethanol**

Competes with oil as raw material to chemicals

# New products of Domsjö

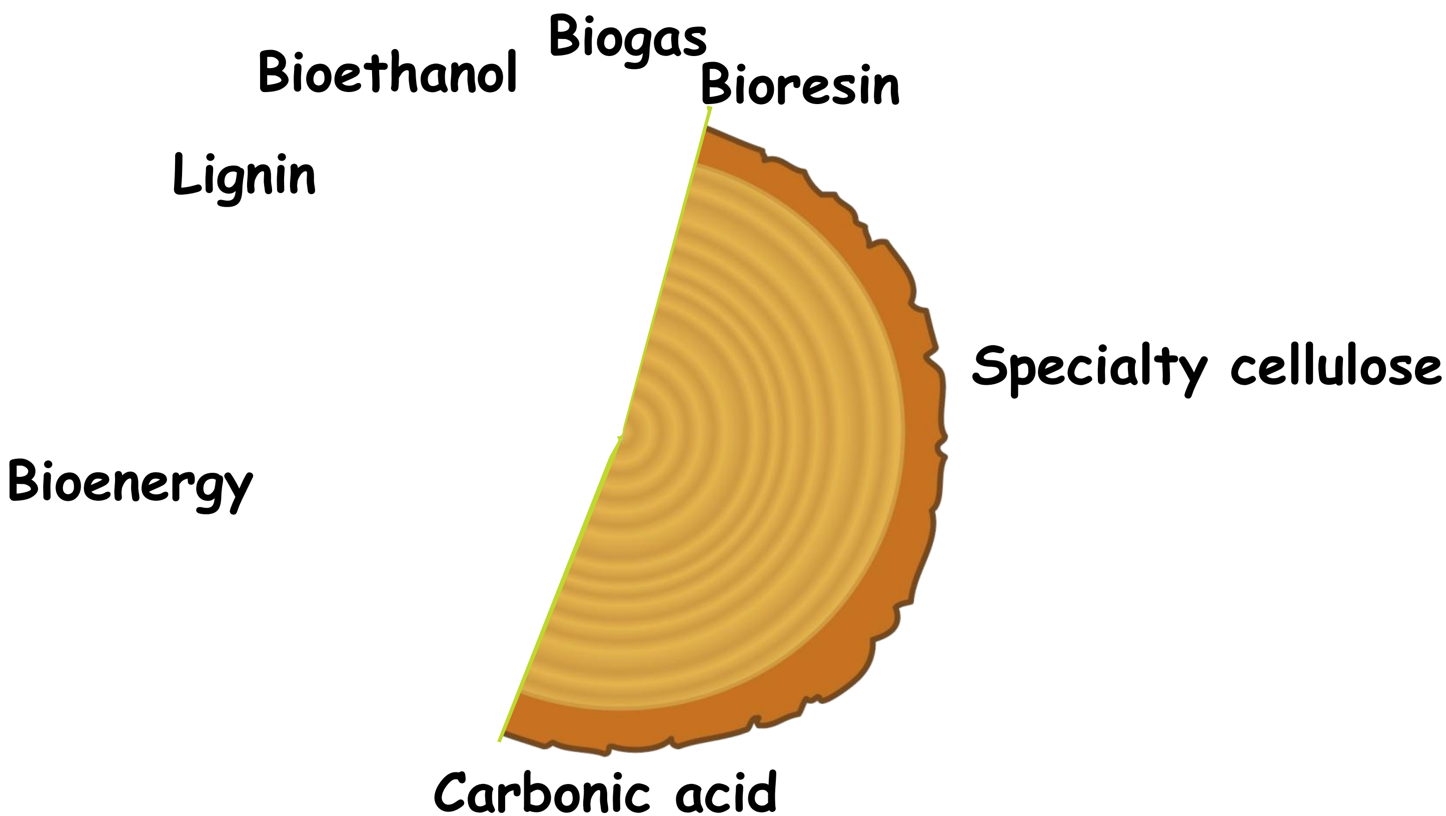
**”Viscose – Comfier than cotton, lovelier than silk”**



*Courtesy of Björn Alriksson, Processum, Sweden*

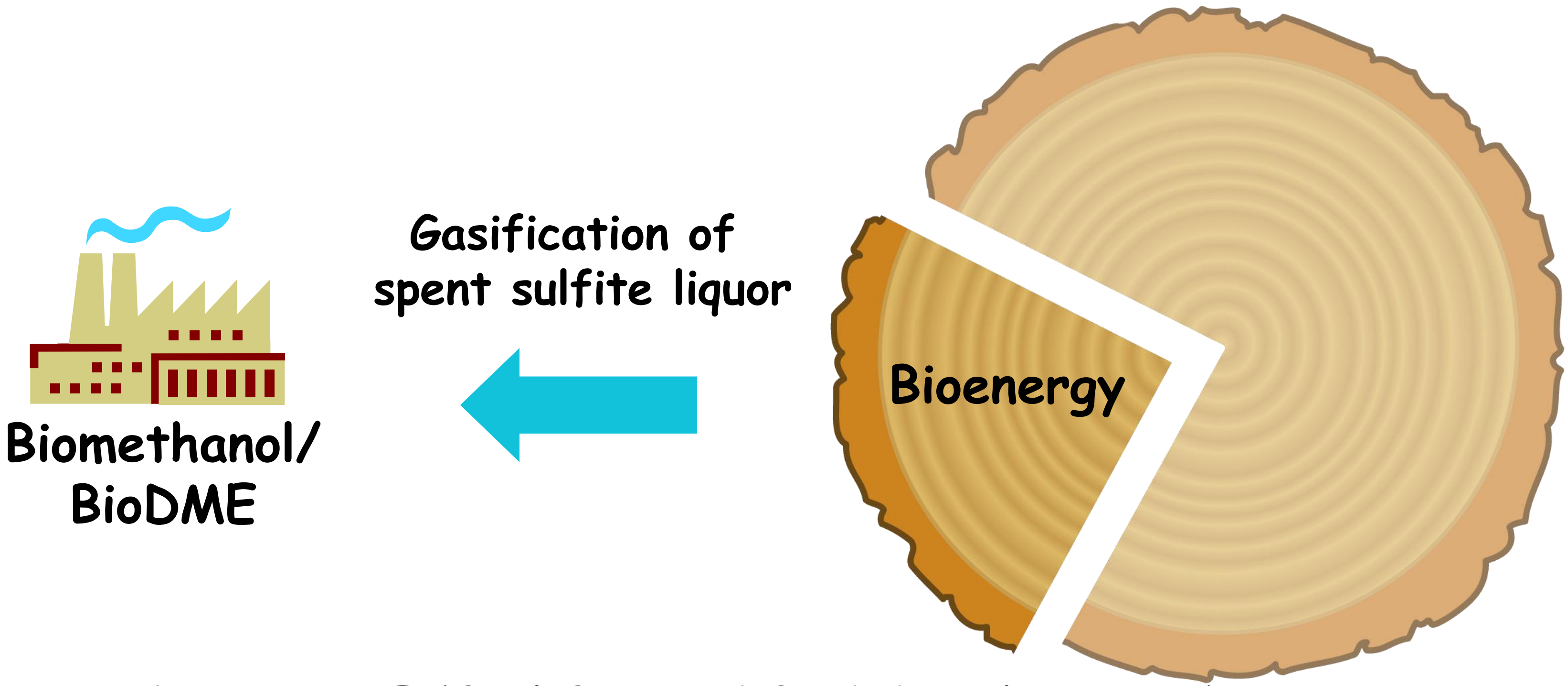
# The products of Domsjö

## Breakdown by turnover




*Courtesy of Björn Alriksson, Processum, Sweden*

# Future increased refining value

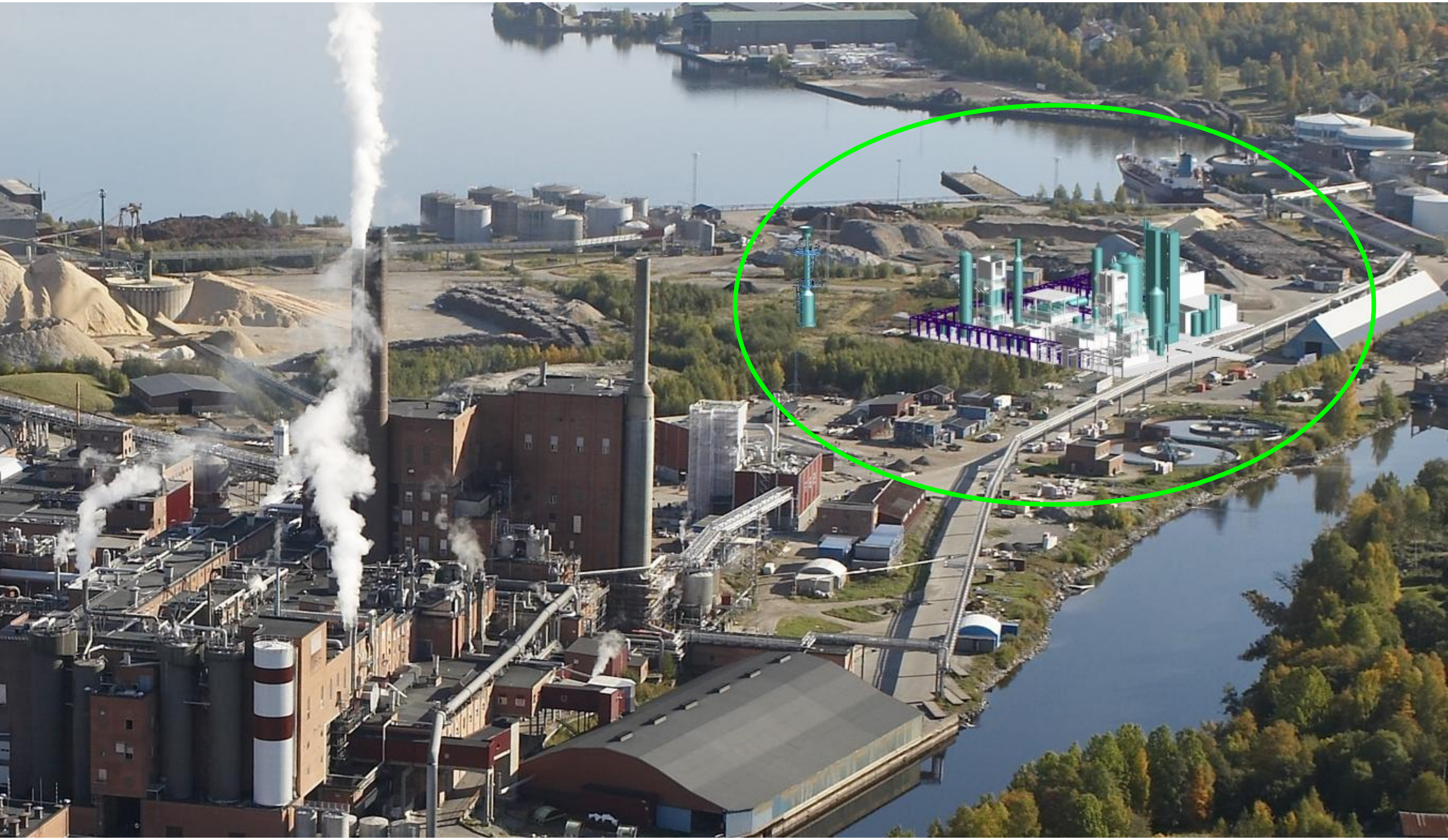



**Two products:** DME (fuel for modified diesel engines)
Methanol (component for gasoline blends)

**Capacity:** 100 000 ton DME per year, enougth to provide fuel for 2000 heavy trucks.

***Courtesy of Björn Alriksson, Processum, Sweden***

# Domsjö Gasification plant om Domsjö in 2014?



***Courtesy of Björn Alriksson, Processum, Sweden***

# Implications for Economic Development

- Bio-refineries tend to source majority of primary inputs from region (local purchases)
- Bio-refineries often face significant permitting processes
- Bio-refineries typically more difficult to fund than single product manufacturing
- Bio-fuels and bio-energy still dependent upon public sector support
- Markets mean everything: Off-take & Input contracts are Key!
- Cost of Capital Increases with Complexity of Project

Courteous of Tim Baye, University Wisconsin / Wisconsin Bioenergy Initiative

# Some Challenges to Biomass Use

- Low cost of fossil based energy
- Financial barriers
  - Difficult to obtain capital for 1st generation bioenergy systems….
- Technology issues
  - Limited long term pilot demonstrations
  - R&D needs to improve performance/efficiency
  - Lack of widely available engineering design firms, technical assistance, tech transfer
- Feedstock availability and cost
- Lack of a level-playing field (compared to petroleum and coal-electricity)

# Other Challenges to Biomass Use

- Access to energy markets
- - feeding distributed electricity generation to the grid (centralized versus de-centralized?)
- Incentives for biobased energy are limited, too specific (*e.g. current IRP offers enormous prices for bagasse??*), not uniformly available
- Poorly informed investors and consumers
- Lack of qualified workforce

# Feedstock Availability and Cost

- Transportation costs
- Availability (seasonal, quality, consistency)
- Supply and demand effects on costs
  - Competing users in agriculture
  - Competing users in forestry
  - Competing users in other sectors
- Quantity - One biodiesel plant could require all available animal fat in Georgia
- Feedstock costs represent from 50-75% of the cost of producing biodiesel

# Centralized versus decentralized bioenergy production

# Centralized or decentralized?

- Here two forces play in against one another: economics of scale and availability of biomass resources.
- **Centralized facilities:** For the production of cellulosic ethanol and application of Fischer Tropsch processes, economics of scale are important. Typically these will be biorefineries from bio-based industries, such as:
  - sugarcane conversion to sugar crystals, bio-ethanol, heat and power.
  - Grain lignocellulosic residues to bio-ethanol, heat and power.
  - Forest products to paper/textile, bio-ethanol, heat and power.
  - SASOL co-feeding biomass with coal.

# Centralized or decentralized?

- However, all these industries required large quantities of biomass, for example green field cellulosic ethanol production should be in the order of 160 ML/annum to be cost-effective.  This would required about 0.6 Mt/annum dry lignocellulosic material (1.2 Mt/annum wet weight)
- Mobile pyrolysis units to convert biomass to bio-oils (2-fold energy-densification on a volume basis) could substantially reduces transportation costs from remote areas to centralized facilities through pumping as liquid.
- One example could be the harvesting of intruder species (of which latest estimates suggest 10+ Mt distributed in mountains and river beds), conversion to bio-oil and pumped to facilities for heat and power for premium markets, or even synthetic fuel production.
- Bio-oil can also be upgraded to transportation-grade fuels, but this is still under development and quite expensive.

# Centralized or decentralized?

- **De-centralized facilities:** the production of bio-electricity and biogas using municipal organic waste, garden clippings and agricultural residues in the vicinity of cities.
- Decentralization can also have great socio-economic benefits, not only diverting waste streams and dealing with intruder species, but could assist in rural job creation and thus combat urbanization.
- The use of agricultural and forestry residues in remote areas can also be used to generate local fuels for cooking (biogas and ethanol gel) and bio-electricity. This has application in remote areas of South Africa, but more particular in SADC countries, for example Malawi where >80% of the population don't have "grid" electricity.

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# Chair of Energy Research: Biofuels and other clean alternative fuels

**Emile van Zyl**

**Johann Gorgens, Marinda Bloom & Hansie Knoetze**

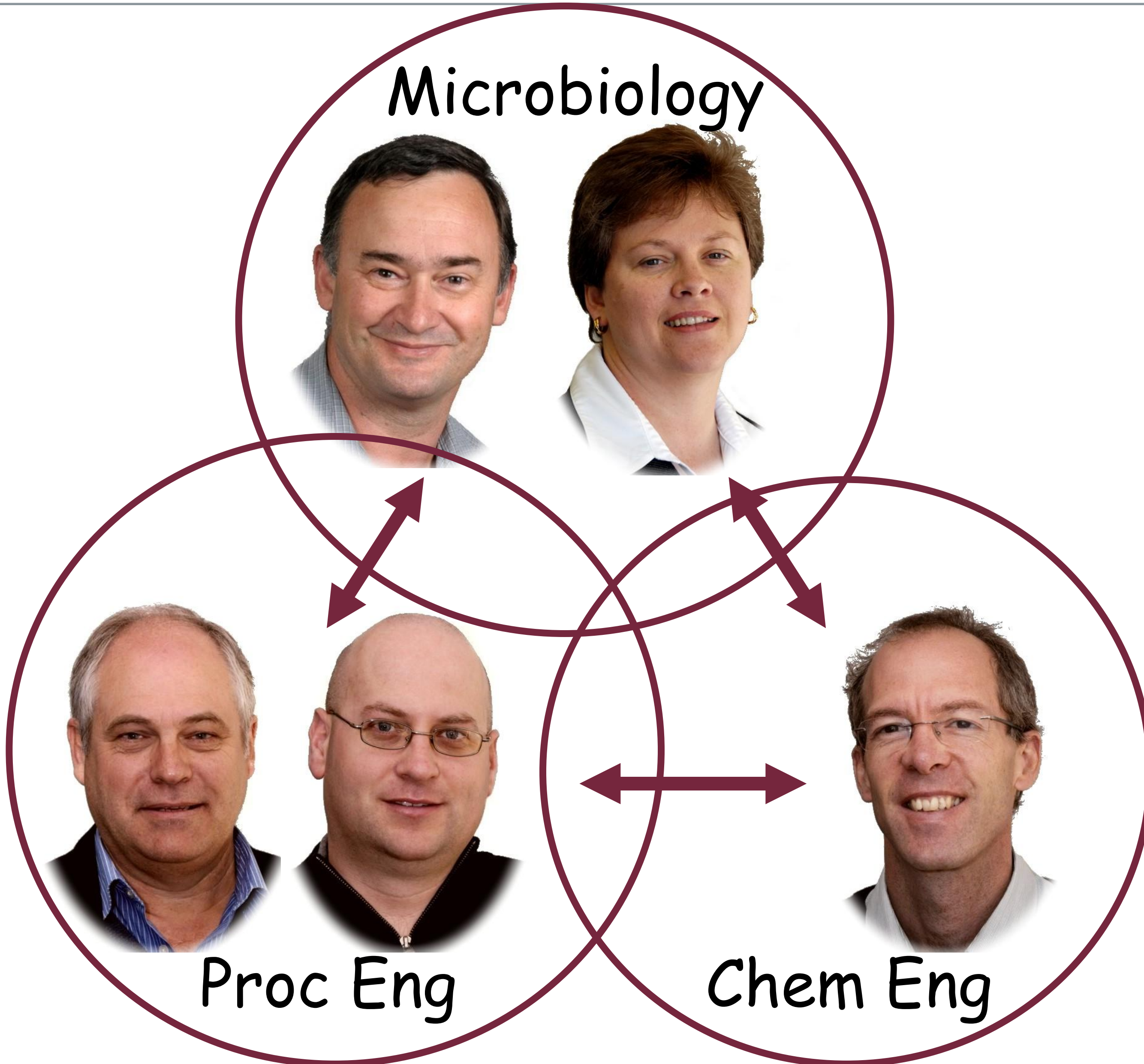
[Stellenbosch University]

&

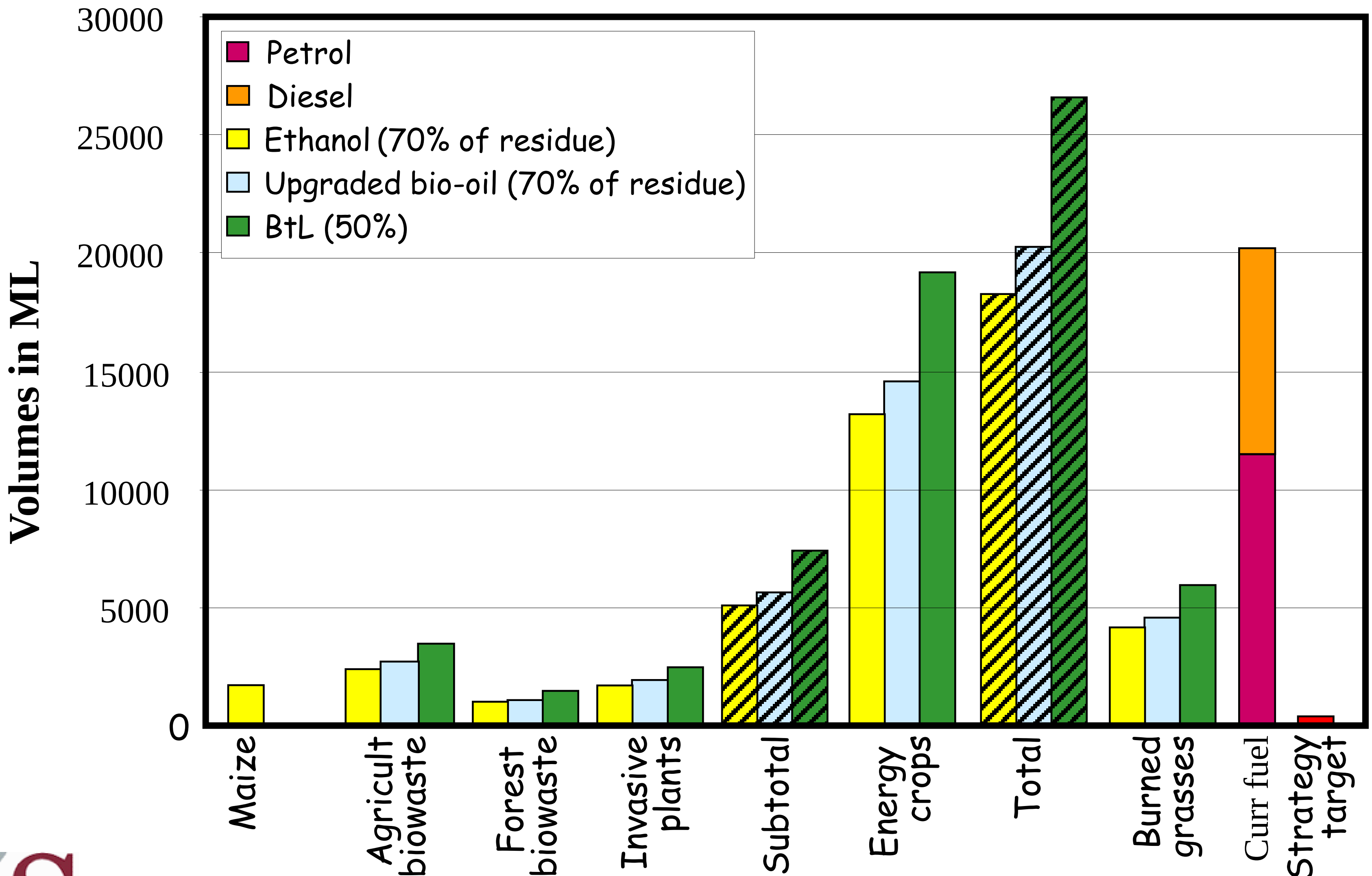
**Harro von Blottnitz**

[University Cape Town]

# CoER : Biofuels (members)



# South Africa's potential: Biofuels production



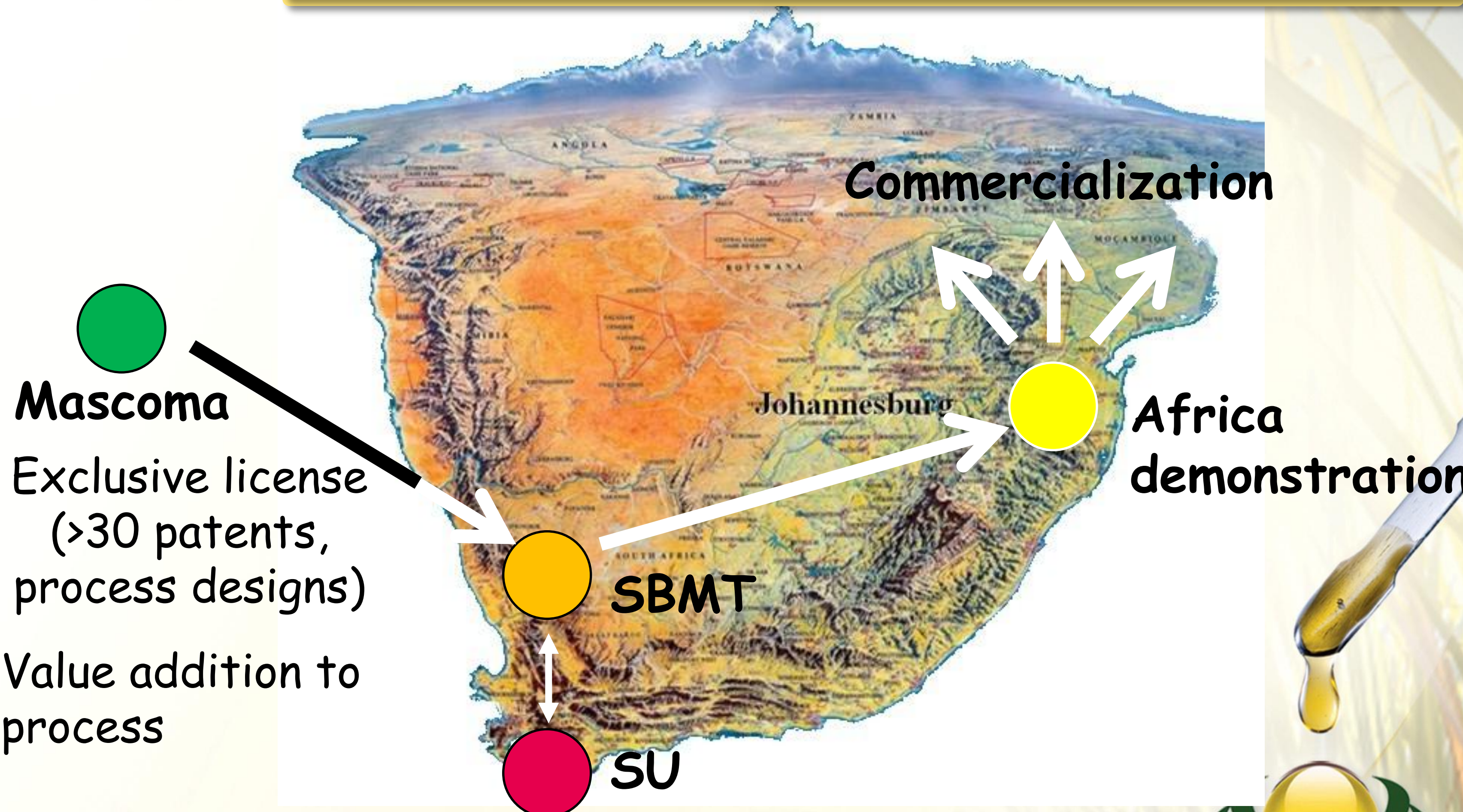

Maize to Ethanol = 430 L/ton

Biomass to upgraded bio-oils = 310 L/ton

Biomass to ethanol = 280 L/ton

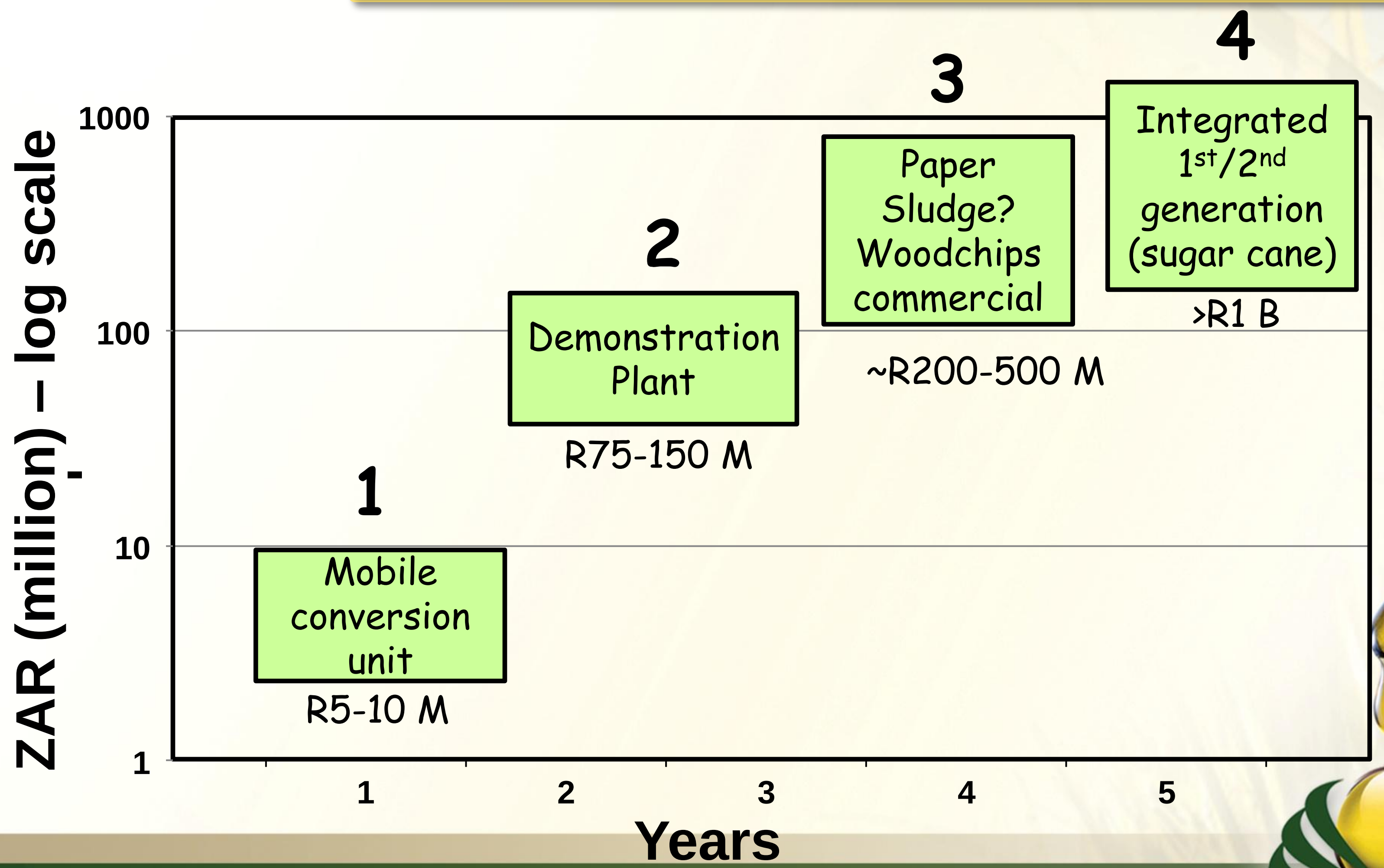
Biomass to liquid (BtL) = 570 L/ton

# SBMT business model




SBMT holds the exclusive rights to Mascoma technology for Southern Africa

# Costs vs timeline for technology development



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# Thank you